

Supersymmetric Contributions to the $B \rightarrow \phi K$ Decays in the PQCD Approach ^a

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ABSTRACT

We study the effects of supersymmetric contribution on both the $B_d \rightarrow \phi K^0$ and $B^\pm \rightarrow \phi K^\pm$ modes using the perturbative QCD approach. We estimate the deviation of mixing-induced and direct CP asymmetries and discuss the strong-phase dependence of them.

1. Introduction

The CP asymmetry of the $B_d \rightarrow \phi K^0$ mode may be useful in the search for new physics beyond the standard model (SM), since it is induced only at the one-loop level. In the SM, the mixing-induced CP asymmetry, denoted by $S_{\phi K^0}$, must be equal to $\sin(2\phi_1)$, which is measured from the CP asymmetry of charmonium modes, and the direct CP asymmetry, $A_{\phi K^0}$, vanishes. Any difference between $S_{\phi K^0}$ and $\sin(2\phi_1)$ would be a signal for new physics. Before the summer in 2004 the Belle collaboration had reported an large anomaly, $S_{\phi K^0} = -0.96 \pm 0.50^{+0.09}_{-0.11}$, while the BaBar result had been $S_{\phi K^0} = 0.47 \pm 0.34^{+0.08}_{-0.06}$ in agreement with $\sin(2\phi_1)$ [2,3]. In the summer in 2004, the both collaborations have given the new results [4,5]: $S_{\phi K^0} = 0.50 \pm 0.25^{+0.07}_{-0.04}$ (BaBar), $0.06 \pm 0.33 \pm 0.09$ (Belle), and $A_{\phi K^0} = 0.00 \pm 0.23 \pm 0.05$ (BaBar), $0.08 \pm 0.22 \pm 0.09$ (Belle). Although the new Belle data of $S_{\phi K^0}$ has moved toward close to the SM value, the data of $S_{\phi K^0}$ seem to be somewhat smaller than $\sin(2\phi_1)$. It might be the effect of some new physics on the $b \rightarrow s$ penguin. Supersymmetry (SUSY) is an attractive candidate for new physics at TeV scale, thus we would like to study the SUSY contribution in the $B \rightarrow \phi K$ modes.

We analyze the SUSY contribution using the mass insertion approximation (MIA), which is a powerful technique for model-independent analysis of new physics associated with the minimal supersymmetric standard model (MSSM). In this approximation, the squark propagators with the $\tilde{b} \rightarrow \tilde{s}$ transition can be expanded as a series in terms of $(\delta_{AB}^d)_{23} = (m_{\tilde{d}_{AB}}^2)_{23}/m_{\tilde{q}}^2$, where $m_{\tilde{d}}^2$ is the squared down-type-squark mass matrix, $m_{\tilde{q}}$ an averaged squark mass. $\{A, B\}$ indicate $\{L, R\}$, which refer to the helicity of sfermions.

A problem lies in the evaluation of hadronic matrix elements. The CP asymmetries, both the mixing-induced and direct ones, depend on the strong phase which is generated from the final-state interactions. However, it is difficult to calculate the decay amplitude including the strong phase. To calculate it, there are several approaches, for example, perturbative QCD (PQCD) [6], QCD factorization (QCDF) [7], and so on. PQCD is based on k_T factorization [8], on the other hand, QCDF on collinear factorization. Each

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method is plagued with large theoretical uncertainties. In this talk, we use the PQCD approach to estimate the MSSM contribution in both the $B_d \rightarrow \phi K^0$ and $B^\pm \rightarrow \phi K^\pm$ modes, and discuss the strong-phase dependence of the results.

2. PQCD Approach for $B \rightarrow \phi K$

A key ingredient of the PQCD approach is the factorization of decay amplitudes into a multiplication of long-distant part and short-distant part. A typical decay amplitude for $B \rightarrow \phi K$ can be expressed as the convolution of a hard part H , meson wave functions Φ_M 's and a Wilson coefficient C :

$$\begin{aligned} \mathcal{M} = & \int_0^1 dx_1 dx_2 dx_3 \int_0^\infty b_1 db_1 b_2 db_2 b_3 db_3 \Phi_K(x_2, b_2) e^{-S_K(x_2, b_2, t)} \Phi_\phi(x_3, b_3) e^{-S_\phi(x_3, b_3, t)} \\ & \times C(t) H(x_1, x_2, x_3, b_1, b_2, b_3, t) \Phi_B(x_1, b_1) e^{-S_B(x_1, b_1, t)}, \end{aligned} \quad (1)$$

where x_i and b_i are the longitudinal fraction of partons momenta and the conjugate variable to the transverse components of them, respectively. The scale t is of order of $\sqrt{\bar{\Lambda} M_B}$ with $\bar{\Lambda} = M_B - m_b$. Here S_M denotes the Sudakov factor. The Sudakov factor ensures the absence of the end-point singularities, thus the arbitrary cutoffs used in QCDF are not necessary in PQCD. As a result, we can predict not only the factorizable contributions but also non-factorizable and annihilation ones, which cannot be calculated in the naive factorization method. A large strong phase is induced from absorptive part in the annihilation diagrams [6]. Although PQCD has large theoretical uncertainties, most of them are expected to be canceled in the ratio when we consider the CP asymmetries. Here we neglect the errors coming from the PQCD method.

PQCD has been applied to the leading-order amplitudes of the $B \rightarrow \phi K$ decays [9] and to the chromo-magnetic penguin (CMP) amplitudes of them [10] within the SM. SUSY contribution comes through the CMP amplitude, which is ambiguous in the naive factorization method because the magnitude of the momentum transferred q^2 by the gluon in the CMP is unknown. In the PQCD and QCDF methods, the CMP can be calculated without any assumption for the value of q^2 . The CMP generates a strong phase from its absorptive part in PQCD [10], since q^2 is written as $(1 - x_2)x_3 M_B^2 - |\mathbf{k}_{2T} - \mathbf{k}_{3T}|^2$, where \mathbf{k}_{iT} 's are transverse momenta of the partons, and q^2 can vanish. On the other hand, in QCDF, q^2 can be written in terms of the momentum fraction of partons too, they however neglect the transverse momenta so that $q^2 = (1 - x_2)x_3 M_B^2$ and q^2 never vanishes. Therefore, there is no absorptive part in the CMP amplitude and the strong phase is not generated from it in contrast with the case of PQCD.

3. MSSM Effects on $B \rightarrow \phi K$

We estimate the gluino contribution to the CP asymmetries for both $B_d \rightarrow \phi K^0$ and $B^\pm \rightarrow \phi K^\pm$ in the single mass-insertion scheme. The LR insertion may change the CP asymmetries of $B \rightarrow \phi K$ significantly even when we constrain the MIA parameters from the branching ratio of $B \rightarrow X_s \gamma$. In the following study, we take a somewhat conservative bound, $2.5 \times 10^{-4} < \text{Br}(B \rightarrow X_s \gamma) < 4.1 \times 10^{-4}$, and the soft masses to be 500 GeV.

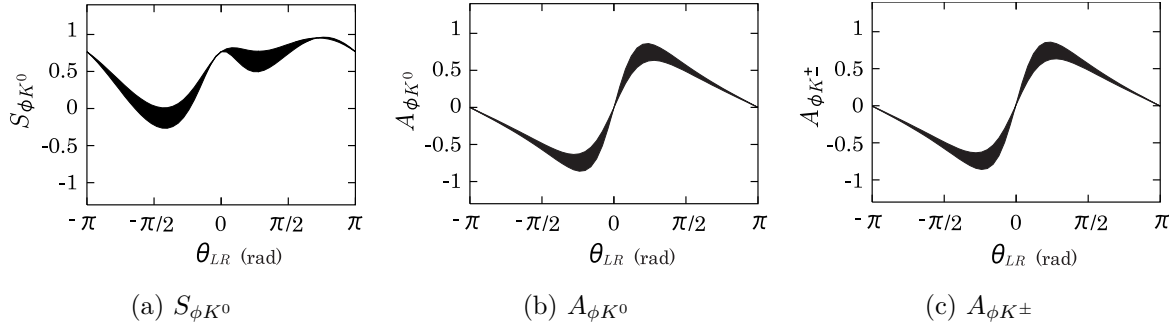


Figure 1: A possible MSSM modification in $S_{\phi K^0}$, $A_{\phi K^0}$ and $A_{\phi K^\pm}$ with the LR mass insertion, which is parameterized as $(\delta_{LR}^d)_{23} = -0.015 + r e^{i\theta_{LR}}$. Here we take $\phi_1 = 25^\circ$ and $\phi_3 = 80^\circ$.

The numerical results in the case of the LR insertion are displayed in Fig. 1. Here the LR insertion is parameterized as $(\delta_{LR}^d)_{23} = -0.015 + r e^{i\theta_{LR}}$, and we scan all values on the allowed region of r . As it can be seen from Fig. 1(a), $S_{\phi K^0}$ may deviate significantly from the SM expectation. This result is almost the same as that using the QCDF method [11]. The result of $A_{\phi K^0}$ and $A_{\phi K^\pm}$ is shown in Figs. 1(b) and 1(c), respectively. $A_{\phi K}$'s arise from the interference between the penguin amplitudes in the SM and the CMP ones in the MSSM. In PQCD, there is a large relative strong phase between them. For this reason, $A_{\phi K}$'s may be large depending on the new physics phase θ_{LR} . It must be noted that the direct CP asymmetry of the neutral mode has the same tendency as that of the charged mode, because the CMP contributions as well as the SM ones are almost the same in both modes. The current experimental data of the neutral mode are shown in the introduction, and those of the charged mode are $A_{\phi K^\pm} = 0.054 \pm 0.056 \pm 0.012$ (BaBar [4]), $0.01 \pm 0.12 \pm 0.05$ (Belle [12]). If we take the result of $A_{\phi K^\pm}$ seriously, there remains only small room for the allowed region of θ_{LR} so that the deviation of $S_{\phi K^0}$ becomes smaller.

Figure 2 shows the strong-phase dependence of the CP asymmetries. Here we parameterize the decay amplitude in terms of a new CP violating phase θ_{NP} , which is correspond to θ_{LR} , and a strong phase δ , which is a relative phase between the SM and new physics amplitudes. The magnitude of the new physics amplitude is taken to be the central value in the LR case. $S_{\phi K^0}$ remains almost stable in the range of $|\delta| < \pi/2$ as shown in Fig. 2(a). As a result, $S_{\phi K^0}$ in our result has the same tendency as that in the QCDF method. In contrast with $S_{\phi K^0}$, $A_{\phi K^0}$ is sensitive to the strong phase and the sign of $A_{\phi K^0}$ is flipped by changing $\delta \rightarrow -\delta$ as shown in Fig. 2(b). In consequence, the QCDF prediction has opposite sign from our result [11]. This fact originates from the difference of the source of the strong phase between the PQCD and QCDF methods. Hence we conclude that more theoretical study is needed for the calculation of the strong phase in order to search for new physics in the direct CP asymmetry of the $B \rightarrow \phi K$ modes.

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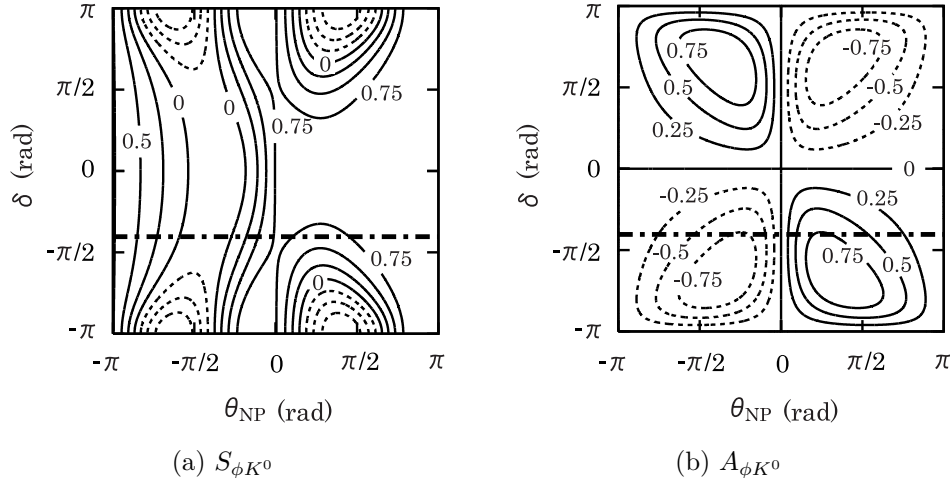


Figure 2: Contour plots of the CP asymmetries in terms of a new CP violating phase θ_{NP} and a strong phase δ , which is a relative phase between the SM and new physics amplitudes. The magnitude of the new physics amplitude is taken to be the central value in the LR case. A step between contour lines is 0.25. Dotted lines represent constant contours with each negative value. Dot-dashed lines denote the PQCD prediction.

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